工業技術研究院
Industrial Technology
Research Institute

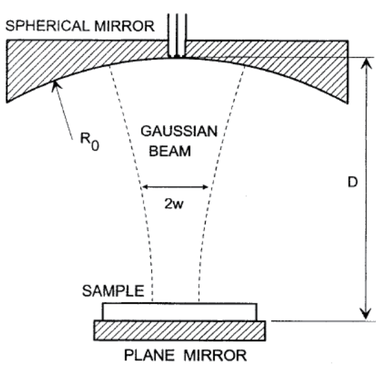
An Automated Open Resonator System for Precision Dielectric Measurement in mmWave

Abstract

A automated open-resonator technique is described for the determination of dielectric permittivity and loss tangent in low-loss dielectric materials at millimeter wave frequency. The resonator is kind of the semiSpherical type and consists of a concave and a plane mirror, and the frequency variation method is used. For precisely specimen position at center of standing wave, system developed an automated high resolution motion to move up specimens in the electric field intensity is the strongest, especially for thin specimen. System measurement accuracy and responsibility have been building by quality evaluation execution. The Gauge Repeatability and Reproducibility (GR&R) evaluated automation measurement system of open resonator demonstrated the high resolution of loss tangent. The evaluation of GR&R measurements was defined system deviation about 5% in permittivity and 10% in loss tangent. The perturbation method made it possible to obtain values of complex permittivity of thin sheet specimens of materials such as polyimide (PI), polytetrafluoroethylene (PTFE) and printed circuit boards (PCB) substrate.

The limitation of Open resonator

Thickness of Sample is Problem



$D < R_0$

General mode

$$\frac{1}{n}\tan(nkt - \emptyset_t) = -\tan(kd - \emptyset_d)\ ;\ \varepsilon_r = n^2$$

thickness ~ λ/2

- Sample thickness about 2mm ~5mm (sheet sample)
- One thickness get the one measurement point

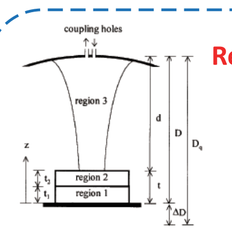
Perturbation mode

$$\varepsilon_r' = 1 + \frac{V}{\alpha\Delta V}\frac{f_0 - f_s}{f_0}$$

thickness < D/1000

- Sample thickness small than 100 um (film sample)
- One thickness get muilti-point measurement in different frequency.

New Design for HemiSpherical Structure



Region 1 define as Air

Boundary condition

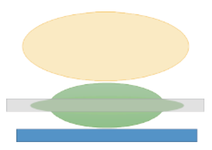
$$\Phi_1 = \arctan\frac{t_1}{n_1 z_0}$$

$$\Phi_2 = \arctan\left[\frac{t_1}{n_1 z_0} + \frac{t_2}{n_2 z_0}\right]$$

$$\Phi_3 = \arctan\left[\frac{d''}{z_0}\right]$$

Equation of solve

$$\frac{1}{n_2}\tan[n_2 kt - \Phi_2 + \beta] = -\tan[kd + \Phi_2 - \Phi_3]$$

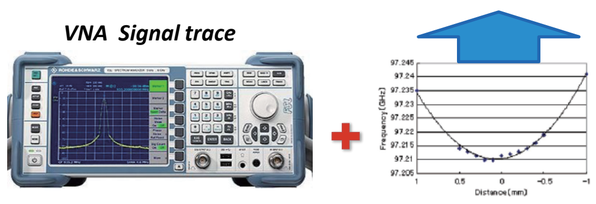


$$\frac{1}{n}\tan(nk(t+h) - \emptyset_1) = -\tan(kd + \emptyset_2 - \emptyset_3)$$

Automation
Measurement system

High resolution motion for lift up sample

VNA Signal trace



VNA signal and motion integration

Conclusions

Uncertainty of System

teflon t = 250um		Uc	K	Expanded uncertainty U	Average	Extended relative uncertainty (%)
28GHz	Dk	0.00519	2	0.01037	2.077	0.499
	Df	0.02024	2	4.047E-05	6.183E-04	6.546
38GHz	Dk	0.00519	2	0.01037	2.070	0.501
	Df	0.01554	2	3.109E-05	5.009E-04	6.206
60GHz	Dk	0.00519	2	0.01038	2.053	0.505
	Df	0.01998	2	3.995E-05	5.500E-04	7.264
77GHz	Dk	0.00519	2	0.01039	2.033	0.511
	Df	0.01753	2	3.506E-05	5.340E-04	6.565

Quartz t = 200um		Uc	K	Expanded uncertainty U	Average	Extended relative uncertainty (%)
28GHz	Dk	0.00519	2	0.01038	4.418	0.235
	Df	0.01228	2	2.456E-05	9.976E-05	24.621
38GHz	Dk	0.00519	2	0.01037	4.415	0.235
	Df	0.01256	2	2.512E-05	1.131E-04	22.202
60GHz	Dk	0.00520	2	0.01040	4.415	0.235
	Df	0.01295	2	2.590E-05	1.539E-04	16.833
77GHz	Dk	0.00521	2	0.01043	4.432	0.235
	Df	0.01196	2	2.392E-05	4.075E-04	5.869

GR&R Result

Permittivity	EV	AV	R&R
28G	0.0105	0.0005	0.0105
38G	0.0333	0.0003	0.0333
60G	0.0578	0.0308	0.0655
77G	0.0618	0.0354	0.0712
94G	0.1290	0.0065	0.1292

Loss tangent	EV	AV	R&R
28G	8.415E-05	2.646E-05	8.822E-05
38G	5.469E-05	2.961E-06	5.477E-05
60G	7.029E-05	6.766E-06	7.062E-05
77G	1.099E-04	1.200E-05	1.106E-04
94G	3.081E-04	1.107E-04	3.274E-04

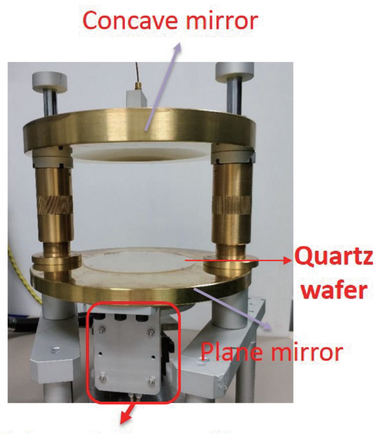
- Measurement Value ± R&R

For Standard sample (Quartz) :
Permittivity = 4.42 ± 0.065@60GHz
Loss tangent = 2.1e-4 ± 7.06e-5 @60GHz

- We achieved new testing method of open resonator for wide thickness range of dielectric Sheet in millimeter-wave band. 50um LCP and 250um Teflon sheet dielectric properties testing in 20 GHz to 100 GHz.
- High resolution auto motion integrated in the dielectrics properties testing system in millimeter-wave, Teflon and Quartz repeatability test with our open resonator system. Loss tangent 0.0001 repeatability at 28 GHz to 94GHz.
- Low loss material is important in millimeter-wave application. Molding compound 、PI substrate、CCL substrate、Ltcc、ceramic etc. will development new material for millimeter-wave application.
- Demonstrates millimeter-wave dielectric properties of package materials at different process temperatures.

Results

New Design for wide thickness range of dielectric sample in mmWave



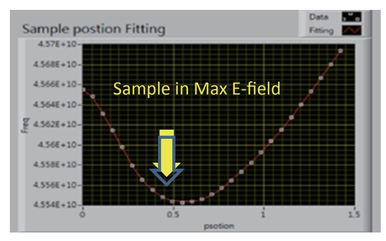
High resolution motion for lift up sample

Motion Resolution : 6 nm
Unidirectional repeatability : 0.018 μm

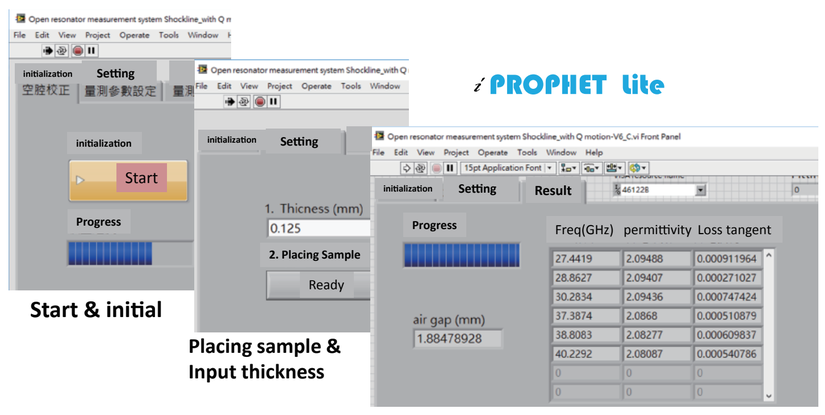
Progress of measurement

1. Getting Resonator parameter : D_q 、R_0 、f_{q0} 、Q_0
2. Insert specimen on plane mirror and setting thickness of sample
3. Start measurement

The automated system accurately moves the sample to the maximum electric field position



Easy Operation Program For Operator



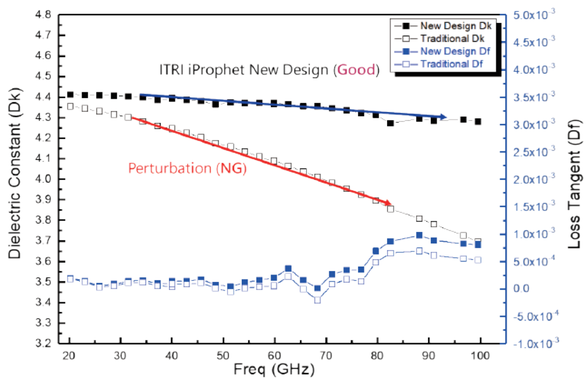
Start & initial

Placing sample & Input thickness

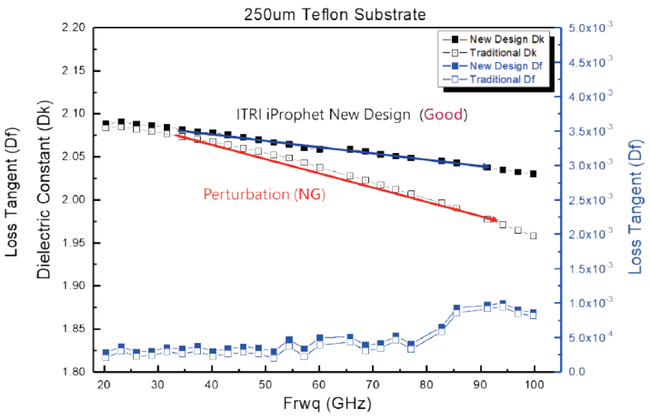
Testing program interface

Measurement & output result (Saved）

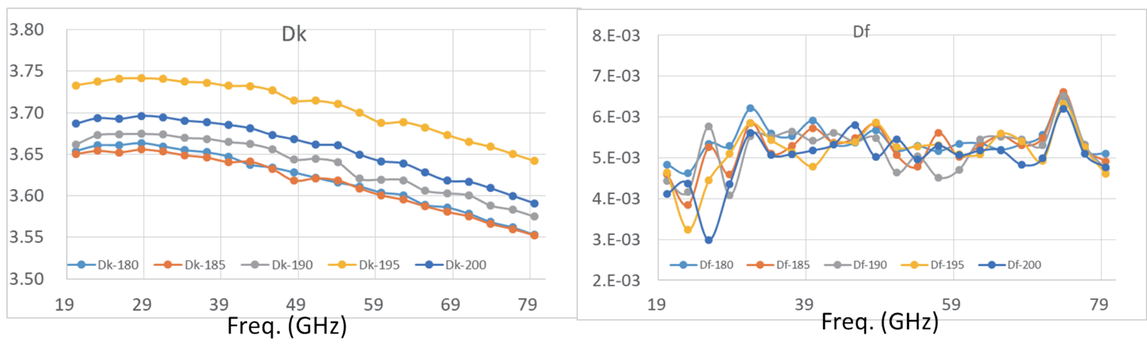
Testing result in 20GHz – 100GHz
200um Quartz wafer



Testing result in 20GHz – 100GHz
250um Teflon Sheet



Low loss molding compound material Dk/Df testing in mmWave



Acknowledge

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Acknowledge

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